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Implementation of a Decision Support Tool for the Development of Centralised Methanation in Abiergué Watershed

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Abstract:- In its commitment to contribute to greater social well-being, to the development of economic opportunities and for the protection of the environment, the Ministry of Environment, Nature Protection and Sustainable Development wishes to study the possibilities of developing a project for the establishment of centralised biogas plant in the Abiergué watershed. It is in this perspective that the present work aimed to determine the most favorable areas for the development of the sector. In order to achieve this objective, the mapping coupled with the multi-criteria analysis was used as decision support tools to identify the most suitable site for the implementation of the unit. The results of the multi-criteria analysis indicate in order of preference the districts Mokolo, Cité verte, Oyomabang, Carrière and Nkolbisson, as the five most favorable areas for the installation of a centralised biogas plant, while districts Etetack, Nkolso'o and Melen, appeared to be the least favorable. The cartographic tool for its part, geolocalises the preferential areas around Oyomabang, Madagascar, Mokolo, Melen, Cité verte and Nkolbikok.

Keywords:- *Methanation; Geographic Information System (GIS); Analytic Hierarchy Process (AHP); Centralised Biogas Plant.*

I. INTRODUCTION

Methanation also known as anaerobic digestion is a process that degrades organic matter into a methane-rich biogas which is currently booming around the world. In Cameroon, the sector is young and promising, benefiting from a financial support system and a regulatory framework conducive to its development. At the national level, this process was initially seen as a way of treating organic waste but its interest in renewable energy production is growing especially in centralised biogas plants where it could also contribute to better nitrogen management and the reduction of greenhouse gas emissions during the storage of animal waste [1].

In the context of the development of these collective anaerobic digestion facilities, the use of agro-food waste, sludge from waste water treatment plants (WWTPs) and catering waste in addition to livestock effluents is common. These different substrates can be collected at varying distances depending on their energy interest. Thus, in order to properly assess the economic and environmental interest of a biogas development project, it is necessary to carry out a preliminary study of available resources, their accessibility and the characteristics of the local economy. For this purpose, a cartographic decision support tool, coupled with a multi-criteria analysis, can be a help for the initial project reflection phase in order to determine the most favorable areas for the development of the sector and to locate preferentially potential resources [2].

II. MATERIAL AND METHODS

A. Presentation of the study area

The selected study area is the Abiergué watershed which includes eleven districts. Located entirely in the city of Yaounde, political capital and seat of the institutions of Cameroon, the watershed of Abiergué is between 3°53'30" and 3°54'00" of latitude North and between 11°26'30 " and 11°30'00 " east longitude. Its area is about 13.5 km^2. Its geographical position is marked by the presence of an urban and peri-urban area. It presents in its urban part a two-unit structure that is the planned area (Cité verte, a portion of Nkolbisson and Oyomabang) and the spontaneous area (Etetack, Nkolbikok, Mokolo, Carrière, Madagascar) [3]. The strong presence of collective housing areas, the numerous households, the data already available on certain resources, the absence of effective sanitation devices are motives that have reinforced the choice for this watershed.

B. Choice of Factors

For our study, only factors or indicators influencing the development of centralised biogas plant and with accessible data were chosen. These factors for which geographic data are available have been classified into four categories (TABLE1). The livestock density per district has the advantage of not giving importance to the size of the district studied. Two types of energy valorization were retained. The first factor used is the electricity transmission network with all the high and very high electric transformer stations. They are a factor in the development of biogas projects by encouraging their implementation in areas constrained by network capacity and reducing the cost of grid connection [4]. The second factor is the set of composting platforms allowing a valuation of the digestate. Since only operating units have a real influence on a site, closed, developing or under study units have been removed from the model. Only one factor was retained concerning the characteristics of the territory. It concerns protected areas of ecological interest where the implementation of any ICPE (all activities industrial or craft industries that can

generate nuisances or present dangers with regard to the environment and third parties) is impossible [5]. This factor was considered as part of territorial particularities because it represents a brake more or less binding depending on the type of protection put in place for the development of a biogas unit. The competition which involves a referencing of all biogas units already existing in the territory is an essential point in the implementation of the mapping tool of this study. An operating biogas plant captures a quantity of inputs which is by definition unavailable for the development of a new project [4]. Prospecting should therefore be done at a distance from these competing units. Only units in operation have a real influence on a site. Closed units either in development or under study have been removed from the model.

Categories	Factor per district	Geography data type
Deposit	Livestock density	Zonal
	Agri-foods industries	Point
	WWTP	Point
	Markets	Point
	Hotels/Restaurants	Point
	Slaughterhouses	Point
Valorization of energy	Electric transformer stations	Point
	Composting platforms	Point
Territorial features	Protected areas of ecological interest	Zonal
Competition	Existing biogas units	Point

Table 1:- Factors considered in our study and their geographic type

C. Determination of the areas of influence of each criterion and weightings of the influence of the spaces with respect to each other

With regard to zonal factors like protected areas of ecological interest, their area of influence is by definition already established [4]. Conversely, for point features, zones of influence have been determined by means of buffer zones more or less consistent. Each criterion is assigned a weight based on its importance. For each indicator, a summary table will be presented, illustrating the different choices of discretization, the attributes used, the areas of influence and the weightings attributed. The choice of weights was made taking into account the economic collection distances and regulatory constraints (natural areas, distances to dwellings, etc.). These weighting coefficients are still arbitrary, they are in no way exhaustive, they may be, as a result of this study, modified, improved as needed.

➢ *Weighting and discretization of point geographic data*

a) WWTPs

WWTPs were initially discretized into three categories according to their capacity (C). Each category was then assigned three areas of influence of decreasing importance with the distance (D) of the point entity concerned. The choice of weights was made taking into account the fact that the valorization of urban sludge in anaerobic digestion can be part of either the treatment of sludge on the site of the WWTP (*in situ* methanation) or as co-substrate to an off-site methanation unit (co-digestion). *In situ* biogas projects are preferred in stations with a capacity greater than 100 000 equivalent-inhabitants (EI). The range of stations between 5 000 and 100 000 EI and especially between 50 000 and 100 000 EI benefits from a technically and financially favorable balance sheet for the territorial methanation installations [6].

WWTP	C < 5000 EI	D < 500m	4
		500m < D < 1km	3
		D > 1km	1
	5000 < C < 100 000EI	D < 500m	5
		500 m < D < 1km	4
		D > 1km	1
	C > 100 000 EI	D < 500m	3
		500 m < D < 1km	2
		D > 1km	1

Table 2:- Weights and discretization of WWTP

b) Hotels and Restaurants

Like WWTPs, hotels and restaurants were initially discretized into four categories according to their number of employees (E). It is assumed that the number of employees of a hotel or restaurant is proportional to the amount of waste produced [6]. Each category was then assigned three areas of influence, of decreasing importance with the distance of the point entity concerned. The choice of weights was also made taking into account the ICPE regulation which imposes a minimum distance of 50 meters between the digesters and the dwellings occupied by third parties, with the exception of dwellings occupied by the staff of the installation and dwellings, including the operator or the supplier of biogas substrates or the user of

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the heat produced at the pleasure. The distance of 50 meters can be increased and extended if possible to 200 meters; the distance range recommended by the ICPE is between 50 meters and 200 meters [5]. Thus, an exclusion zone has been rigorously defined for a distance of 200 meters around these entities. In this zone, the implementation of a biogas unit is simply prohibited.

Hotels/Restaurants	E < 10	D < 200m	0
		200m < D < 500m	3
		500 <D <1km	2
		D > 1km	1
	10 < E < 30	D < 200m	0
		200m < D < 500m	4
		500 < D < 1km	3
		D > 1km	1
	30 < E < 50	D < 200m	0
		200m < D < 500m	5
		500 < D < 1km	4
		D > 1km	1
	E > 50	D < 200m	0
		200m < D < 500m	6
		500<D <1km	5
		D>1km	1

Table 3:- Weights and discretization of hotels and restaurants

c) Markets and Electric Transformer Stations

Contrary to the previous characters, the markets were not the subject of a first discretization. An area of influence was simply attributed to them. This choice has been made because although markets can represent significant quantities of methane waste, they are often packaged or mixed with various other non-biodegradable waste. They must undergo a mechanical-biological sorting which represents an additional cost. Markets do not yet significantly impact methanation, waste from agro-industry and livestock are currently largely preferred [4]. The electric transformer stations were simply allocated a buffer zone of 1 km, with two different weighting coefficients because beyond this distance, the connection cost is considered too high.

Markets	D < 500m	5
	500m < D <1km	4
	D > 1km	1

Table 4:- Weights and discretization of markets

Electric transformer stations	D < 1km	3
	D > 1km	1

Table 5:- Weights and discretization of electric transformer stations

d) Existing biogas plants and composting platforms

Only the proposed methanation units have been identified in the Abiergué watershed. Since only operating units exert a real influence on a site, units under development, under study or in project have been removed from the model and are not subject to weighting. Like the existing biogas units, only planned or closed composting platforms have been identified in the Abiergué watershed. Only the composting platforms in operation are considered in our study, they were also not weighted.

- *Weighing and discretization of the zonal geographical data*

a) Protected natural areas - Land cover

The land use weights were assigned according to their presence or not in the territory (TABLE 6). If it is difficult to implement an anaerobic digestion unit on a site, the weighting factor assigned is low or even zero. A coefficient null is synonymous with exclusion. These surfaces will no longer be taken into account within the model. The land use by areas such as protected natural environments, water surfaces or artificialized green spaces in no way allows the development of methanation units. On the other hand, industrial or commercial zones and agricultural areas represent very favorable areas for the establishment of biogas-producing factories so, their weights are high.

Land use	**Presence**		
	Protected natural areas	If yes	0
	Water areas	If yes	0
	Artificial green spaces	If yes	0
	Open spaces, without or with little vegetation	If yes	1
	Forest	If yes	2
	Agricultural areas	If yes	4
	industrial areas	If yes	5

Table 6:- Weights and discretization of land use

b) Livestock density

Livestock density is the only quantitative zonal geographical feature of the study. Its discretization is thus organized in a particular way. This one was based on the discretization by arithmetic progression. This method is designed for asymmetric and extended distributions with many low values and few strong values [7]. We pose:

Amplitude a = Class number × *R* (1)
With *R = (value max - value min)/(1+2+3+…)* (2)

Where R: extended dynamic of the series

The weights are then assigned to each class and grow with the livestock density.

Livestock density per district	L<193	1
	193 < L < 359	2
	359 < L < 609	3
	L> 609	4

Table 7 :- Weights and discretization of livestock density

D. Mapping of weightings and final mapping

The use of a global positioning system (GPS) was done to obtain the coordinates of the point data. Maps representing the geolocation of the different indicators as well as their respective weightings were established using the QGIS 2.18 software. A final map of deposits, energy outlets and territorial features is then obtained by superimposing all the geographical layers, in order to add their different weights.

E. Analytic hierarchy process

The analytic hierarchy process method [2] [7] was used for our study in order to find preferential districts for the implementation of a centralised biogas plant in the Abiergué watershed then, to classify them from the most favorable to the less favorable. The graphical representation, in tree form (Fig. 1), shows the hierarchical structure of our study which took into account four criteria among which criteria C3 was subdivided into three sub-criteria as presented in Fig. 2. The districts of the Abiergué watershed that represent the different alternatives were organized in alphabetical order, then we assigned a number to each of them (Fig. 2). The judgment matrix of the different alternatives was established according to their respective characteristics obtained on the basis of the estimation of the potential of the deposit, the geolocation of the factors of influence of the development of the methanation, the field investigations, the bibliographic review [2] [3] [8] [9]. The data on the accessibility rate of roads at the different districts of the Abiergué watershed as well as the density of habitat come from the work of [10]. From the sums obtained for each district, a preferential ranking is established. A district with the highest final score is a preferred site for the implementation of the biogas unit.

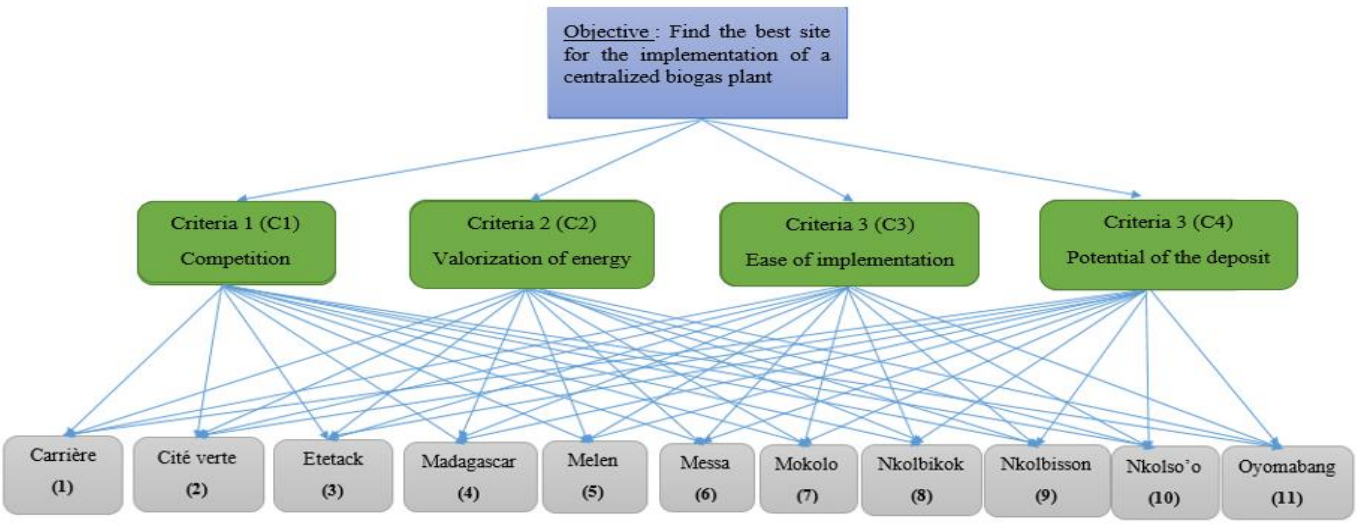

Fig. 1:- Overview of the hierarchical structure of the problem.

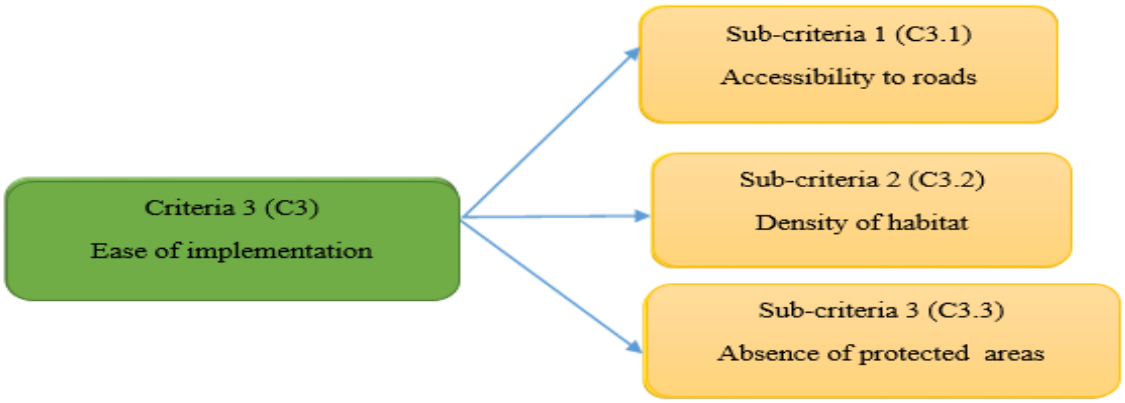

Fig. 2 :- Subdivision of criteria C3 into sub-criteria

III. RESULTS

A. *Mapping of the various indicators selected*

➢ *Indicators for the deposit*

Livestock density are unevenly distributed in the catchment area as shown in Fig. 3. The highest numbers of animals are found in the districts Nkolbisson and Oyomabang where pig farming dominates. Then come Etetack, Madagascar and Melen where although the breeding is notorious, it is nonetheless present in some farms. The smallest population is recorded in the district Cité verte.

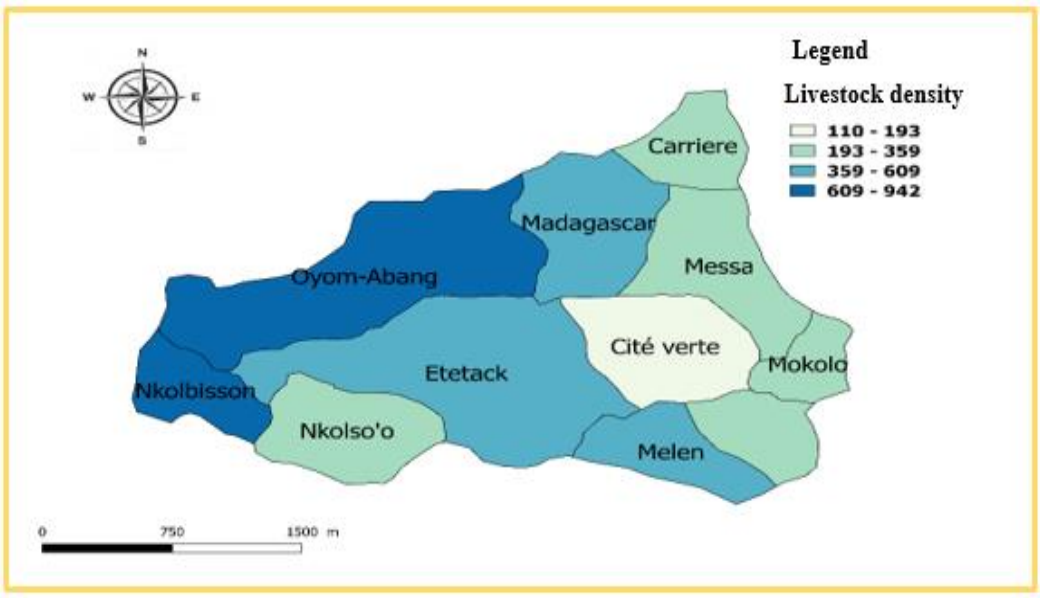

Fig. 3 :- Livestock density per district

Fig. 4 presents the geographic distribution of point-specific data for the deposit in the Abiergué watershed. This map integrates the hydrographic and road network which also influence the development of centralised anaerobic digestion. Regarding the location of all these geographical entities of the deposit, we can see that, in general, no district presents them all at once. While in some areas there is a strong presence of hotels, restaurants and markets (Melen, Nkolbikok, Mokolo), others are totally lacking. This is the case of Messa, Nkolso'o, Carrière, Cité verte. The districts where there is a strong presence of these entities are essentially part of the urbanized area and these are mainly located along the main roads in order to be in contact with the consumer. On the other hand, districts where hotels, restaurants and markets are few or nonexistent are characterized for some by a large uninhabited area (Nkolso'o, Carrière Madagascar). For the WWTPs, only two districts have: Cité verte and Messa.

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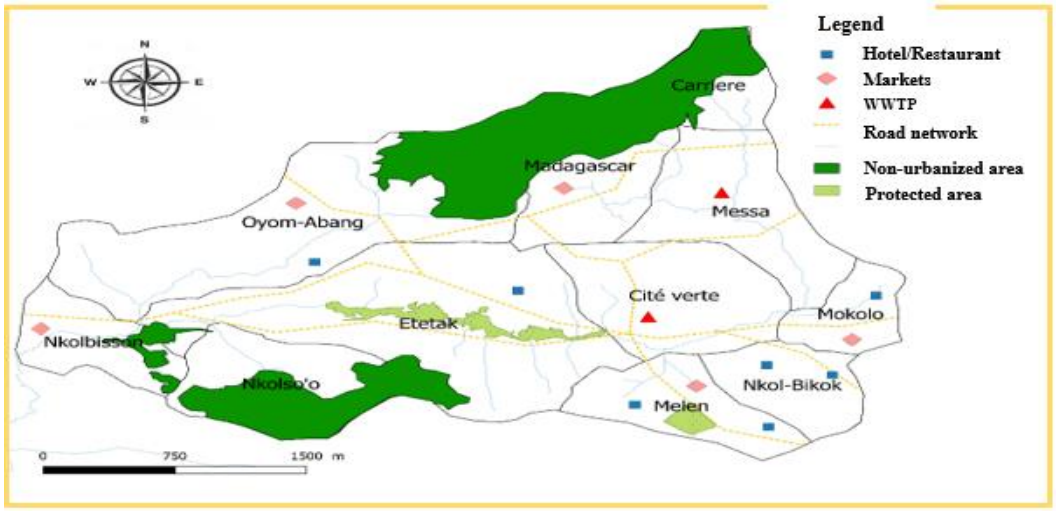

Fig. 4 :- Distribution of WWTPs, markets, hotels, Restaurants in the Abiergué watershed

➢ *Indicators for the valorization of energy and territorial particularities*

The electric transformer stations are present in two districts on the watershed: Nkolbikok and Oyomabang. The Nkolbikok network has lower maximum operating voltages than Oyomabang. There is no composting platform in operation in the Abiergué watershed. Protected natural environments are of different types in the catchment area and consist of urban forests and zoos. The largest is probably the zoo-botanical park of Melen. These protected natural areas are also located along the roads.

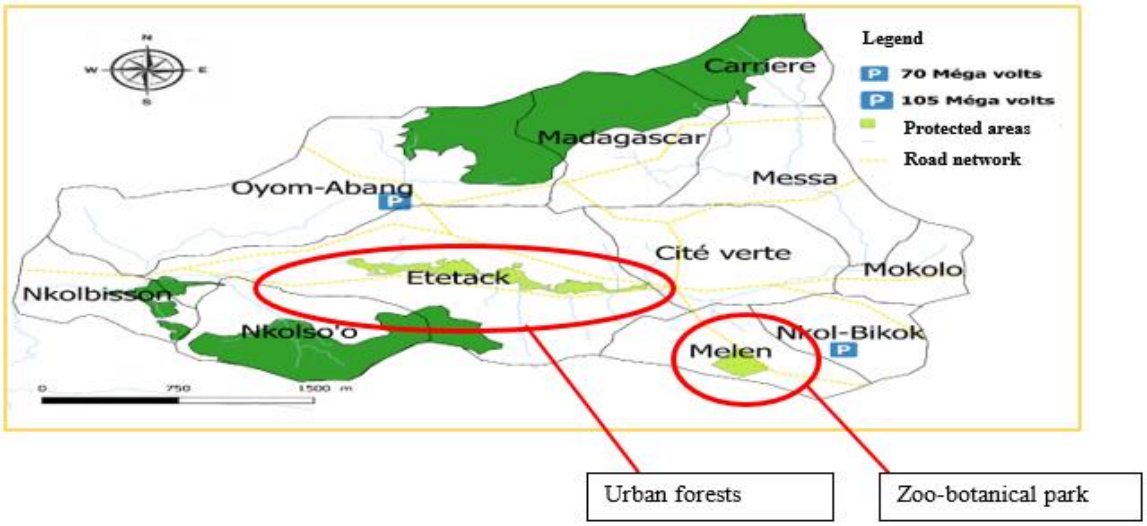

Fig. 5 :- Electric transformer stations - Composting platforms - Protected Natural Areas.

➢ *Competition*

There was no methanation unit in operation identified in the Abiergué watershed. Recall that our study did not take into account the units in the course of project, development or closed.

B. Mapping of the weights of every factor influencing the methanation

Maps will show the distribution of the zones of influence (buffer zones) of each indicator with a legend of the weights assigned to each of these zones. A buffer zone with a high rating or a high weight indicates a more favorable space for the implementation of one methanation unit, compared to another of less weighting. Zero weighting indicates the exclusion zones for which the implementation of an anaerobic digestion unit is impossible or prohibited.

➢ *WWTPs*

Fig. 6 shows the influence areas of the WWTPs. Compared to this deposit, Nkolbisson, Nkolso'o, Etetack and Oyomabang districts are at a disadvantage for the establishment of the methanation unit unlike Cité verte, Melen, Messa, Madagascar or Carrière which are located within a radius of 1km maximum the different WWTPs of the Abiergué watershed.

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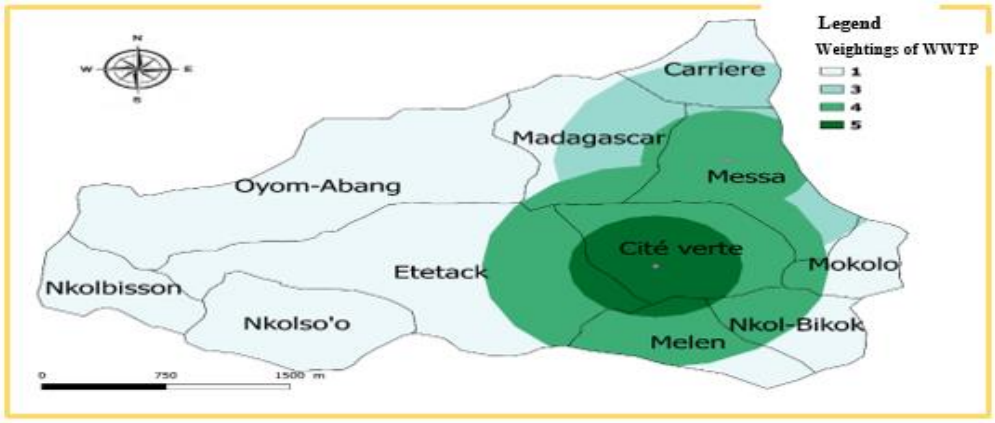

Fig. 6:- Map of WWTP's weightings

➢ *Markets*

Fig. 7 shows the areas of influence of the markets. These are weak in the districts Nkolso'o, Career and to a lesser extent, Etetack and Messa. On the other hand, the districts Mokolo, Madagascar, Oyomabang, Melen, Nkolbisson present the strongest areas of influence.

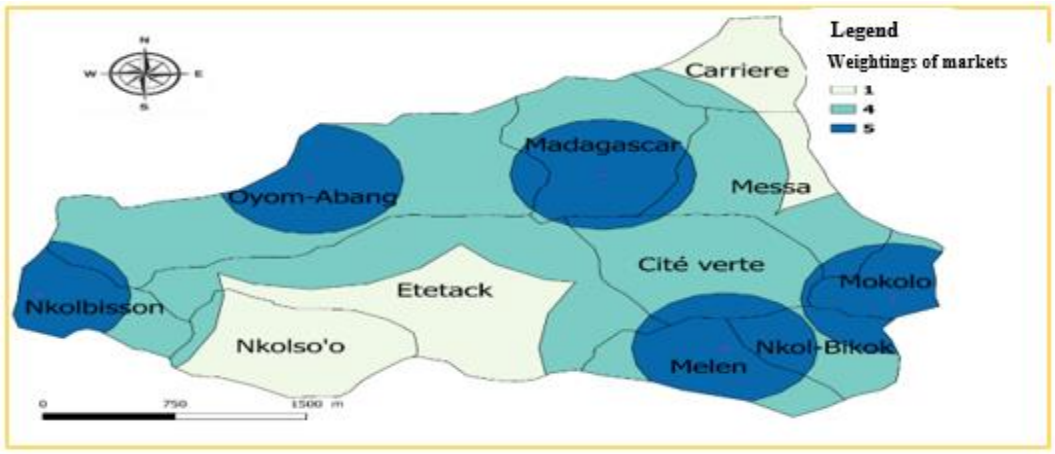

Fig. 7 :- Map of markets weightings

➢ *Hotels and restaurants*

Fig. 8 shows the areas of influence of hotels and restaurants. For these indicators, Nkolbisson, Nkolso'o, Madagascar, Carrière (located in the peri-urban area) and Messa (administrative district) are at a disadvantage for the implementation of a methanation unit in relation to in the Melen, Nkolbikok, Mokolo, Etetack and Oyomabang districts where there is a strong presence of these indicators.

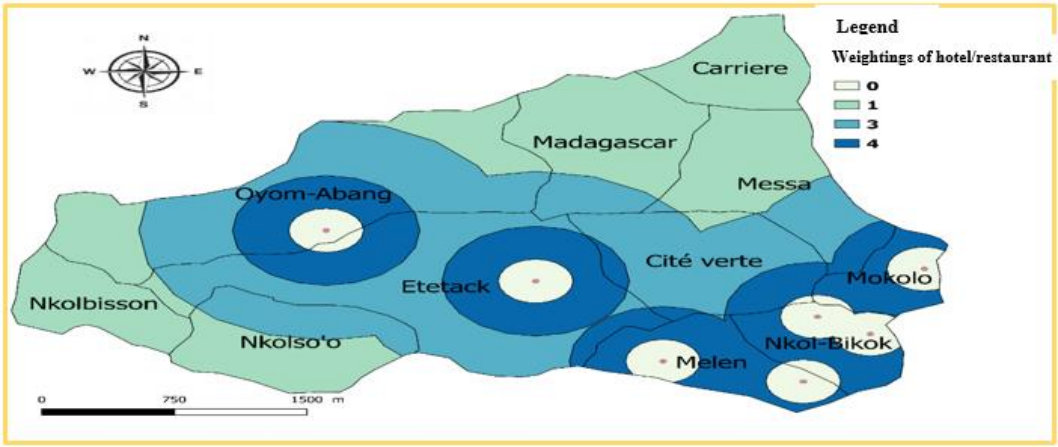

Fig. 8:- Map of hotels and restaurants weightings

➢ *Electrical transformer stations*

Fig. 9 shows the areas of influence of the transformer stations around their anchorage point in the Abiergué watershed. We observe that the districts Oyomabang, Etetack, Melen, Mokolo, Nkolbisson, and even Cité verte benefit from good points relating to the valorization of biogas in electricity.

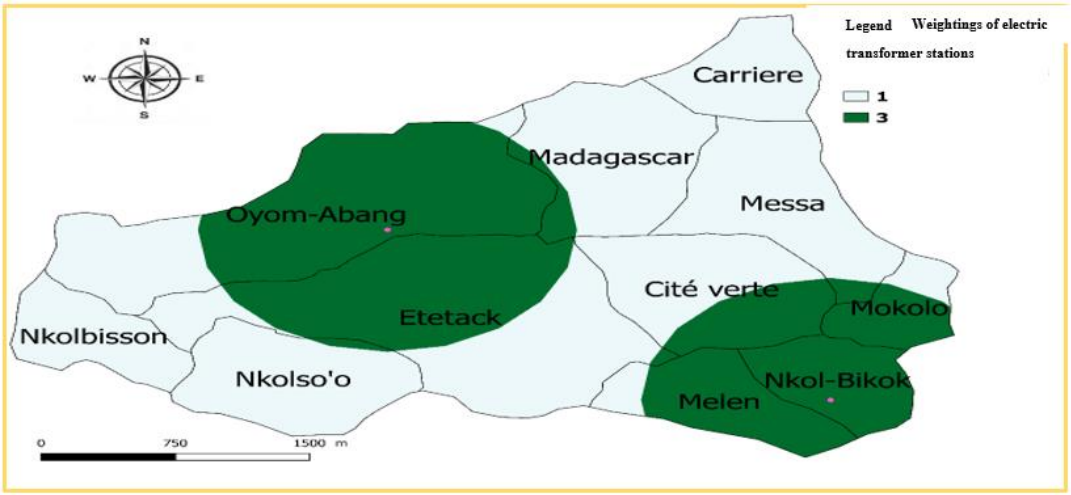

Fig. 9:- Map of electric transformer stations weightings

➢ *Land cover*

The land cover map (Fig. 10) shows exclusion zones where any installation of an anaerobic digestion unit is prohibited. Thus, the rivers represented by the hydrographic network, the urban forests at Etetack and the zoo at Melen are sites excluded from the model. The non-urbanized areas of the Abiergué watershed (Carrière, Madagascar, Nkolso'o, Nkolbisson) which are essentially agricultural areas, are favorable to the establishment of an anaerobic digestion unit and will allow the valorization of the digestate by spreading. Zones with weighting 1 represent open spaces with little or no vegetation which in the absence of particular constraints and according to their local characteristics appear as suitable sites for the installation of an anaerobic digestion unit.

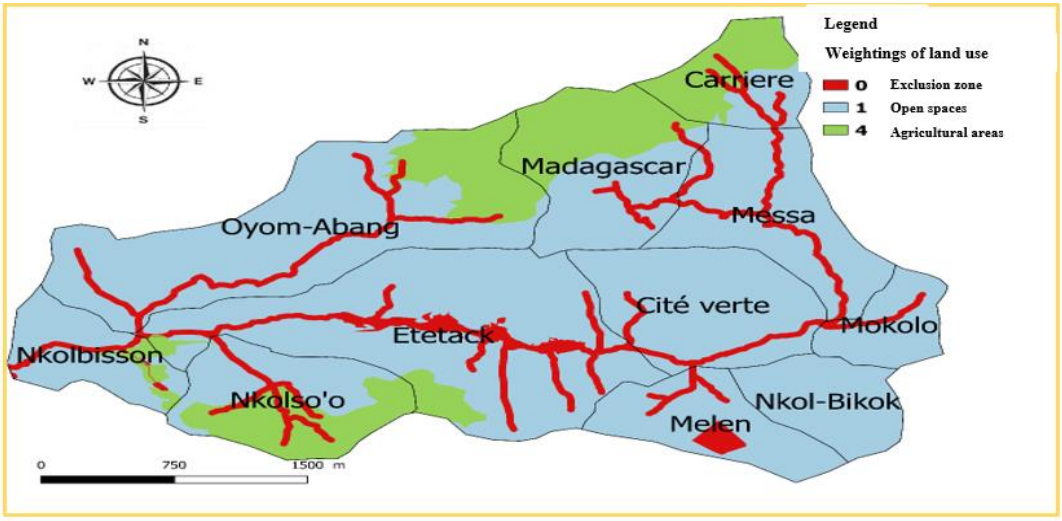

Fig. 10:- Map of land use weightings

➢ *Livestock Density*

Fig. 11 shows the weights assigned to livestock numbers. The more pronounced the breeding is in a district the more it favors the development of anaerobic digestion.

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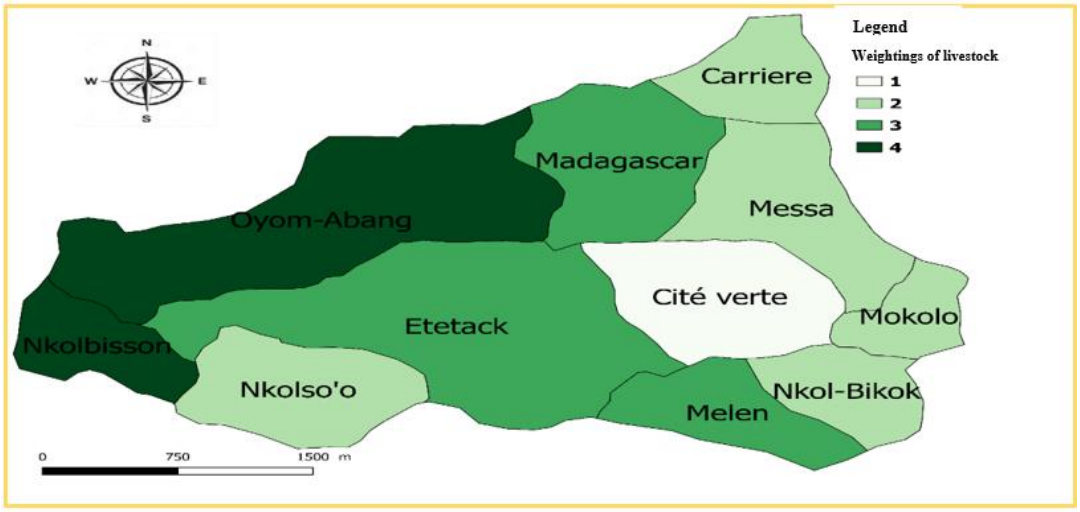

Fig. 11 :- Map of livestock density weightings

➢ *Final mapping of areas favorable to potential biogas*

The final map (Fig. 12) illustrates the development potential of anaerobic digestion over the entire Abiergué watershed. There is a high index of potential around districts Mokolo, Cité verte and Melen but also districts Oyomabang, Madagascar and Etetack due to the presence of massive deposits such as households, markets, hotels and restaurants. Transformer stations useful for the connection of electricity also reinforce this trend. Peri-urban areas are also concentrated in districts with a high index. This is the case of Nkolbisson, Oyomabang or Madagascar. This final map obtained serves as a first result. It allows to locate roughly where to concentrate the prospecting approaches on the scale of the eleven districts without providing clear information on the preferential areas for the implementation of our centralised methanation unit.

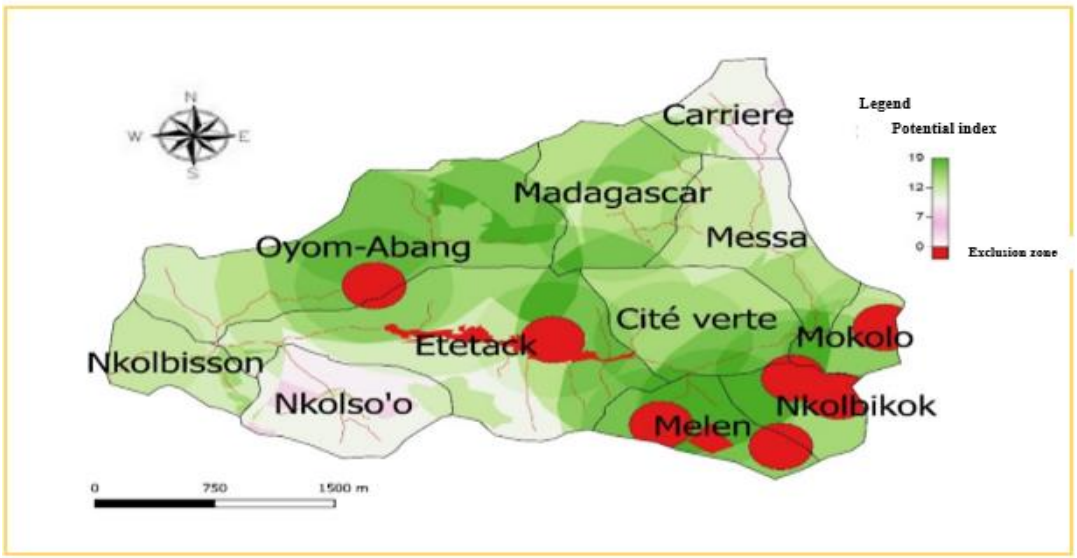

Fig. 12 :- Potential for the development of centralised biogas plant in the Abiergué watershed.

C. Results of the multi-criterial analysis

The final result of the multi-criteria analysis taking into account all the criteria of our study thus gives an overview of the classification of the districts in order of preference for the implementation of the central methanation unit. It then makes it possible to refine the decision as to the optimal choice of a biogas production site. Thus, the district Mokolo is positioned in the first place. This choice seems judicious, not only in relation to its own potentialities (presence of a large market, access to roads, production of a large amount of household waste, etc.) but also because of its proximity to the potentialities of surrounding areas (Cité verte's WWTP, Nkolbikok's processing Station, hotels and restaurants, etc.). These results make it possible to reinforce the observations made from the cartographic tool where it is noted that these districs have areas with a high index of potential.

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District	C1	C2	C3			C4	Final note
			C3.1	C3.2	C3.3		
Mokolo	0.006	0.011	0.005	0.005	0.024	0.099	0.151
Cité verte	0.006	0.011	0.003	0.012	0.024	0.079	0.135
Oyomabang	0.006	0.021	0.003	0.009	0.024	0.036	0.098
Carrière	0.006	0.011	0.007	0.011	0.024	0.032	0.092
Nkolbisson	0.006	0.011	0.006	0.007	0.024	0.036	0.090
Madagascar	0.006	0.011	0.003	0.013	0.024	0.032	0.089
Messa	0.006	0.011	0.005	0.011	0.024	0.020	0.076
Nkolbikok	0.006	0.020	0.003	0.005	0.024	0.008	0.065
Etetack	0.006	0.011	0.005	0.011	0.005	0.024	0.062
Nkolso'o	0.006	0.011	0.005	0.005	0.024	0.008	0.059
Melen	0.006	0.011	0.003	0.012	0.005	0.020	0.057

Table 8:- Results of the multi-criteria analysis.

IV. DISCUSSION

This tool is intended to be extended throughout the Cameroonian territory and to directly locate the area most conducive to the development of anaerobic digestion in regions that are still little concerned. The methodology of this tool can also be extended in the field of wind power, solar energy or wood boilers, once the relevant cartographic data have been identified and are available. Some criticisms can be made about the tool put in place especially regarding weightings or the choice of data. They can certainly be specified or improved. For hotels and restaurants, it would have been possible to adjust the weights by taking into account more criteria. The number of employees is a correct variable but it could have been associated with the standing of the establishment in question as well as with information on the methanogenic potential of the waste produced. Regional characteristics are also to be taken into account which could make it possible to perform additional precision depending on the region studied. The weights assigned are the same over the entire studied territory so, the model chosen does not take into account the specificities of the territory. It is thus implicitly considered that it is homogeneous. The question arises then about the size of the territory to be taken into account to set up this type of tool. Here the choice was chosen for a watershed but the question remains whole. The national scale with a taking into account of specificities can it be envisaged? Regarding the land use, it must be remembered that the model does not take into account residential areas. The accuracy of the data is therefore relative. They do not represent the actual limits of a zone of activity or an industrial zone. Nothing can therefore be said that the regulation of residential areas (favorable to the development of biogas units) therefore applies effectively to the areas referenced within the tool put in place. This reinforces the tendency to adapt the tool to smaller geographical features such as a watershed. It should also be noted for the valuation part, that it would have been important to integrate low and medium voltage transformer stations which are more present in the area and therefore more favorable to connection. Finally, with regard to the natural areas data, it should be noted that the weightings of these areas do not add up when in the same territory, the presence of several types of protection is proven. Only the protection with the lowest weighting predominates. However, the regulations diverge, and it is certainly more difficult to adapt a project when a natural area of ecological interest, fauna and flora of type 2 [11] is present and a regional nature park for example. The need to take into account this superimposition of the different types of protection of natural areas must therefore be taken into account to improve the proposed tool.

V. CONCLUSION

Geolocation of influencing factors to the development of centralised biogas plants makes it possible to obtain an aptitude map which takes into account a realistic collection distance for each resource and which also takes into account regulatory constraints (natural areas, distances to dwellings, etc.). The multi-criteria analysis method that made it possible to designate the Mokolo district as the most favorable for the implementation of this development project, proved in itself, a structured approach complementary to the cartographic tool in order to organized all the information relevant to the assessment of the potential of a biogas production center. Additional studies were carried out to estimate the methanogenic potential of the deposit of each of the eleven districts of the Abiergué watershed and on the preliminary technical and economic feasibility of the project. The methods developed in this study are intended to be extended over the entire territory and will thus make it possible to locate directly the most favorable areas for the development of the sector. An extension of the work undertaken could be to valorize the data acquired at very specific scales for generalization purposes to larger territories and to combine geographic information system and life cycle analysis, the ultimate goal being to build a model maximizing energy recovery from bio-resources in conjunction with low environmental impact.

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